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A Narrowband Mid-infrared Absorber with Tunable Peak Absorbance and Nearly Unchanged Peak Wavelength Using a Phase Changing Material

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A Narrowband Mid-infrared Absorber with Tunable Peak Absorbance and Nearly Unchanged Peak Wavelength Using a Phase Changing Material

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Abstract. A narrowband mid-infrared (MIR) absorber with tunable peak absorbance and nearly unchanged peak wavelength is demonstrated using a phase changing material. The absorber is formed by an Au IR reflector, a SiO₂ dielectric cavity and a 1D photonic crystal that consists of SiO₂ and GeSbTe (GST), which is a phase-transition material and thus controls the absorbance without static power consumption. The dimension of the Au/SiO₂/GST/SiO₂ are optimized for high peak absorbance, high quality factor and low background absorbance. The as-fabricated absorber with amorphous GST shows the peak absorbance of 0.704 at 5.636 μ m, quality factor of 46.19, and background absorbance less than 0.02. Without significantly changing the absorption peak wavelength and background absorbance, the peak absorbance of the absorber can be tuned up to 4.47 dB by the phase transition of GST. Such tunable narrowband MIR absorber is a promising candidate for low-cost thermal emitter for infrared applications.

1. Introduction

Mid-infrared (MIR) region plays an important role in many fields such as gas sensing [1,2], bio-detection [3] and astronomy [4]. As 3-8 μ m is the spectral range where many organic molecules have fingerprint regions [5]. A power tunable, narrow band light source in this range is needed in these applications. Light emitting diodes (LEDs) and laser diodes (LDs) have been widely used as narrowband light sources in the visible and near infrared range [6], but the counterparts in MIR range such as quantum cascade lasers (QCLs) are usually difficult to fabricate and expensive as they rely on intersubband transition which generally needs more than hundreds of quantum wells [7].

Another type of such light source is the narrowband thermal emitter, which is based on the selective absorber with a narrowband absorption peak and low background absorption according to Kirchhoff's law. Various types of selective absorbers have been demonstrated in recent years, among which are metamaterial emitters [8-12], multi-quantum well (MQW) structures [13, 14] and phase-changing materials (PCMs) [15-17]. Metamaterial emitters enable single- or multi-band selective emission, but they usually have wide absorption band and need complex nano-pattern, moreover, their absorbance is difficult to adjust [8-12]. The selective absorbers with MQW structures can provide a narrow band emission with tunable absorbance, but they involve high-cost semiconductor epitaxy and



the adjustment of absorbance needs a sustained electric consumption [13, 14]. PCMs such as GeSbTe (GST) have been introduced to control the absorbance due to their different optical constants in different phases without the need of static power consumption to maintain the different absorbance, but the absorbers suffer from significant peak wavelength changes and broadband absorption [15-17].

Here we propose and demonstrate a narrowband, absorbance tunable MIR absorber by the tandem films that include an Au IR reflector, a SiO₂ dielectric cavity and a 1D photonic crystal that consists of SiO₂ and GeSbTe (GST). The peak absorbance of the absorber can be controlled by the phase transition of GST without significantly changing the absorption peak wavelength and background absorbance.

2. Materials and Methods

2.1 Design and Fabrication

As shown in Figure 1, the absorber is formed by an Au IR reflector, a SiO₂ dielectric cavity and a 1D photonic crystal that consists of SiO₂ and GeSbTe (GST), which is a phase-transition material and thus controls the absorbance without the need of static power consumption. The dimension of the Au/SiO₂/GST/SiO₂ are optimized for high peak absorbance, high quality factor and low background absorbance. Firstly, the thickness of each layer of photonic crystal was given by $n \cdot d = \lambda/4$, where n is the refractive index, d is the thickness and λ is the peak wavelength. The complex refractive indexes of a-GST and c-GST were measured by ellipsometry method, and that of SiO₂ is from Ref. [18]. The peak wavelength is set as 5.5 μm , thus the thickness of GST and SiO₂ layer in 1D photonic crystal is $d_{\text{gst}} = 330 \text{ nm}$ and $d_{\text{SiO}_2} = 1065 \text{ nm}$, respectively. Then the thickness SiO₂ cavity (d_{cavity}) was optimized to maximize the interaction between the Au IR reflector and 1D photonic crystal at the peak wavelength, and the corresponding $d_{\text{cavity}} = 2130 \text{ nm}$.

The tandem films of the absorber were deposited by the combination of magnetron sputtering (MS) and plasma enhance chemical vapour deposition (PECVD) after the cleaning of Si substrates. Firstly, a thin Ti adhesion layer ($\leq 10 \text{ nm}$) was deposited followed by the deposition of Au IR layer on the substrate via magnetron sputtering. Then GST and SiO₂ were deposited by MS and PECVD, respectively. The as-deposited GST was amorphous (a-GST), and a 30-min annealing process at 210 °C was carried out to crystallise GST(c-GST).

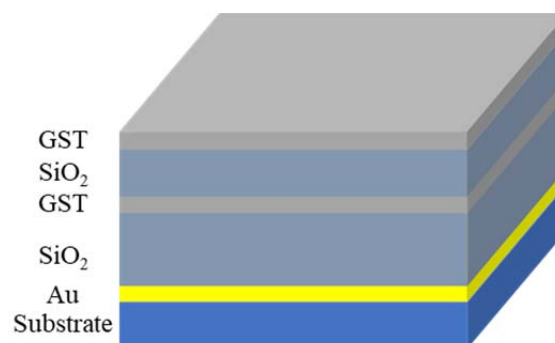


Figure 1. Schematic of the absorbance tunable MIR absorber

2.2 Measurements

The complex refractive indexes of a-GST and c-GST were measured with J.A. Woollam IR-VASE MARK II ellipsometer. The normal reflectance was measured with Bruker Vertex 80 FTIR with a DTGS detector. Because the gold film is sufficiently optically thick ($>200 \text{ nm}$), there is no transmission in the absorber and the absorbance (α) and the reflectance (R) satisfies the relationship: $\alpha = 1 - R$. The dimensions of tandem films were measured by Zeiss Merlin scanning electron microscope. The phase of individual GST layer was characterized by the Bruker D8 ADVANCE X-ray powder diffractometer which is operated at 40 kV voltage and 40 mA current with Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$).

3. Results and Discussion

Figure 2 shows the normal absorbance spectra of Au/SiO₂/GST/SiO₂/GST absorber. For a-GST case, the peak of absorption is 0.7041 at 5.6357 μm and the full width at half maximum (FWHM) is 122 nm, giving a Q factor 46. The absorber has an extremely low background absorbance (0.008 at 4.75 μm) contributed by the large stop band formed by 1D photonic crystal of SiO₂/GST. For c-GST case, the peak of absorption is 0.2514 at 5.7866 μm and the FWHM is 251 nm, giving a Q factor 23. And the absorber keeps almost the same background absorbance (0.006 at 4.75 μm). Since there is little change of the absorption peak wavelength, this structure achieves an absorption controlling of 4.47 dB near the designed peak wavelength by the phase transition of GST.

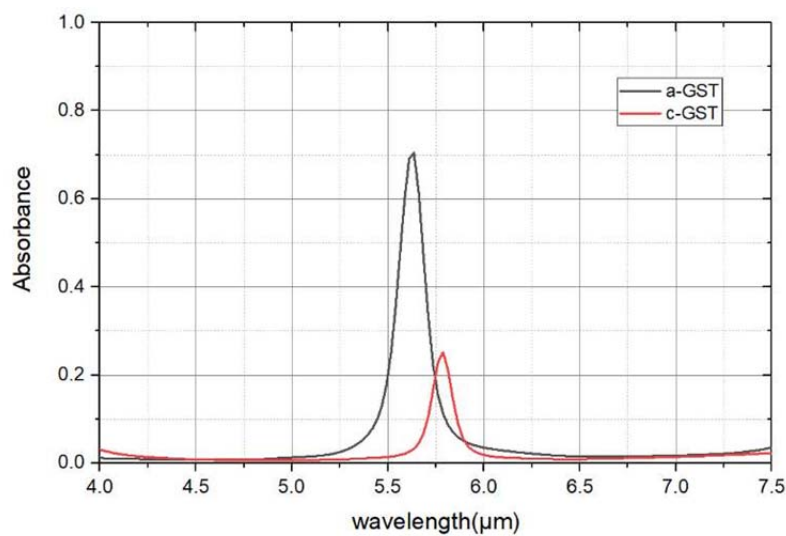


Figure 2. Measured normal absorbance spectra of Au/SiO₂/GST/SiO₂/GST MIR narrowband absorber

Figure 3 shows the XRD patterns of an individual GST layer deposited by magnetron sputtering with same process parameters to that of Au/SiO₂/GST/SiO₂/GST MIR absorber. There is no clear diffraction peak before annealing, which means that the as-deposited GST is nearly amorphous. Three diffraction peaks appear in the XRD pattern of annealed samples, indicating GST has transferred into crystalline phase.

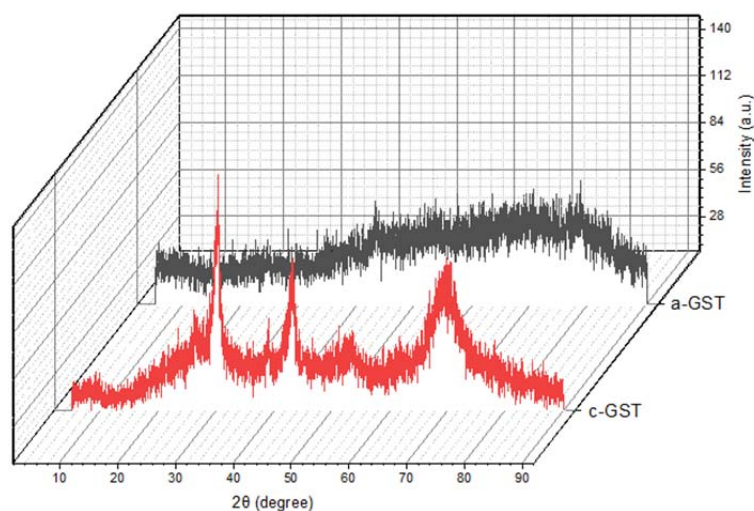


Figure 3. The XRD patterns of the GST layer before and after annealing

Figure 4 shows the SEM cross-section image of the tandem films of Au/SiO₂/GST/SiO₂/GST with the observation elevation of 45°, giving the corresponding thickness of individual layers of $d_{\text{gst}} = 270$ nm, $d_{\text{SiO}_2} = 1078$ nm and $d_{\text{cavity}} = 2156$ nm. The boundaries of individual layers are clear but not smooth enough, and the thickness of GST deviates from the optimized value slightly. Those imperfections need further improvement for better performance of the selective narrowband MIR absorber.

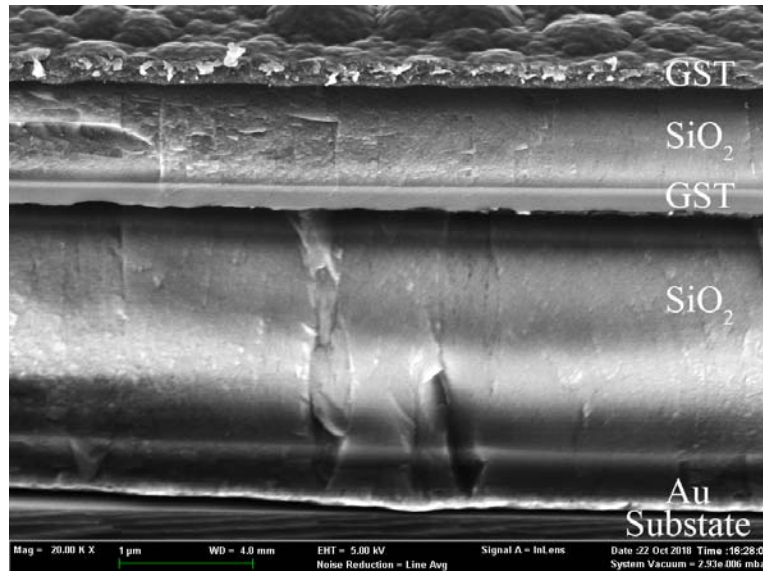


Figure 4. SEM cross-section image of the tandem films of Au/SiO₂/GST/SiO₂/GST

4. Conclusions

A lithography-free, narrowband mid-infrared (MIR) absorber with tunable peak absorbance and nearly unchanged peak wavelength is demonstrated using the tandem films of Au/SiO₂/GST/SiO₂/GST. The as-fabricated absorber with amorphous GST shows the peak absorbance of 0.704 at 5.636 μm, quality factor of 46.19, and background absorbance less than 0.02. Without significantly changing the absorption peak wavelength and background absorbance, the peak absorbance of the absorber can be tuned up to 4.47 dB by the phase transition of GST. Such tunable narrowband MIR absorber is a promising candidate for low-cost thermal emitter for infrared applications.

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6. References

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